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High-resolution spatial surveys using AUVs

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Improved productivity stems from pinpoint positioning

In the last decade, smaller unmanned underwater vehicles have seen expanded operational roles. Underpinning this productive use are reliable navigation and positioning, leading to optimised operations, expanded capabilities, and greater cost-effectiveness. A prime example is more effective spatial surveys, gathering accurately-located environmental data. These surveys vary from addressing specific questions to sampling oceanic properties or imaging seabed structures. Survey output is often a high-resolution georeferenced map, showing water composition, seabed biota, or unexploded ordnance.

For 25 years, Teledyne RDI Doppler velocity logs have been an industry-leading solution for accurately measuring a vehicle's speed and altitude over the seabed. The high precision and fast update rates of data from these DVLs have enhanced subsea operations from pipeline surveys and ROV stationkeeping to high-resolution spatial surveys. Pinpoint positioning improves not just the vehicle's trajectory, but the quality of data and images gathered at high sampling rates. Plus, repeatable positioning is essential when areas are remapped to see changes – as a part of securing ports, monitoring invasive species, or gauging hypoxic dead zones.

Other vehicle missions can be more targeted, such as detecting and tracking a contaminant plume, mapping its dispersion, or finding its source. In these cases, vehicles must measure water flow and concentrations of chemical or

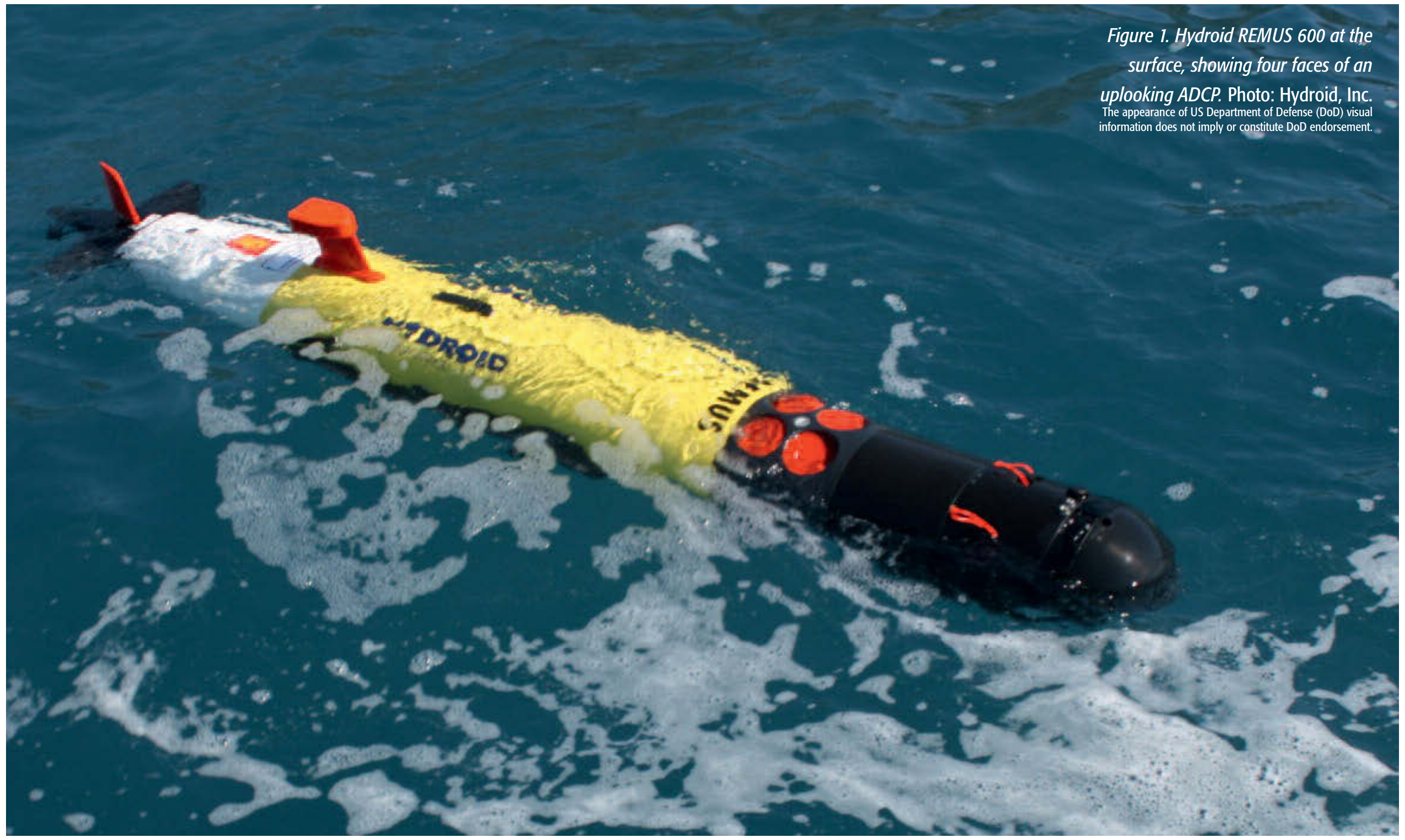

Figure 1. Hydroid REMUS 600 at the surface, showing four faces of an uplooking ADCP. Photo: Hydroid, Inc.
The appearance of US Department of Defense (DoD) visual information does not imply or constitute DoD endorsement.

biological content. Vehicles fitted with Teledyne RDI DVLs can use the embedded ADCP for measuring water currents at many depths simultaneously, sometimes above and below the vehicle.

In fact, subsea missions aiming to discover sources are an active research area, combining onboard control of a vehicle's path with adaptive sampling strategies. One goal is improving a vehicle's use of time and energy. An obvious candidate is less need to surface for communications. Improved efficiency also requires not just gathering data but in-situ processing; for instance, Teledyne's hydrographic product CARIS Onboard.

In this article, we'll look at two studies of coastal waters where reliable navigation and positioning of subsea vehicles contributed to successful results. Plus, we'll review a deep-sea search where relocating vehicle position was crucial.

PLUME TRACKING

Discharge and runoff from land to the ocean – both directly and through estuaries – have come under scrutiny worldwide. This attention is motivated by deteriorating marine ecosystems, worsened by pollutants and excessive nutrient loading. Quantifying how effluent and water properties are transported and spread will help to advance understanding of their impact on coastal waters.

For addressing these goals, small autonomous underwater vehicles are seeing more action. In work off Southern California, researchers from Scripps Institution of Oceanography used an AUV for detecting and mapping plumes from ocean outfalls. The work studied the plume's rise and thickness as well as its rate of dilution. At the same time, the scientists wanted to develop a more reliable and efficient method for routine monitoring of discharge plumes, especially for assessing plume direction.

While the AUV moved at 1.75 metres per second, the up- and down-looking Teledyne RDI ADCPs profiled water currents each second. Transects of velocity observations were merged by using a statistical method of 2D interpolation that output depth-averaged currents on a uniform spatial grid. Patterns in these maps, such as a large eddy circulating around a discharge outlet, revealed interactions between intrusive currents and ambient flows, as well as helping to explain structure in contour maps of water properties.

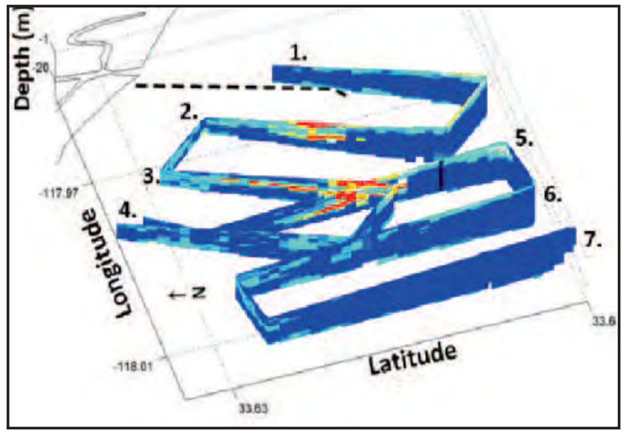

Figure 2. AUV path during a survey of a discharge plume. Warm colours indicate location of effluent.
Image: Rogowski, P. and E. Terrill, IEEE/OES CWTM Workshop 2015. DOI:10.1109/CWTM.2015.7098122

During one survey, currents in an outfall's receiving waters were initially along the coast. Later, the currents reversed direction, causing the plume's path to stall.

Such changes had bedeviled workers using cast-based sampling from boats. Some of this uncertainty is lessened with the continuous data records along an AUV's path.

Accurate navigation, including precise bottom tracking from a Teledyne RDI DVL, was essential in these surveys for repeating a circuit at different depths in the near-field, for travelling on reciprocal paths, and for optimising a search for a plume far from its source.

COASTAL MIXING

Off the west coast of Scotland, researchers from the Scottish Association for Marine Science examined coastal mixing associated with brackish plumes that emerge from a sea loch on each ebb tide. The scientists found that the plume's moving frontal

AUV spatial surveys

Many AUV-based coastal surveys observe both flow fields and water properties continuously and concurrently. By flying an undulating path, AUVs record data in both vertical and horizontal directions for various sensors. As well, these surveys can be flexible, adapting them via underwater communications to change a vehicle's track if conditions vary from those anticipated during mission planning.

Autonomous underwater vehicles provide a cost-effective means for establishing baseline values and then evaluating changes caused by mixing events, such as internal tides or hurricanes. Repeating AUV-based spatial surveys – both successively and at different times – is a productive way to see properties spread, to identify mixing hot spots, and to clarify driving factors.

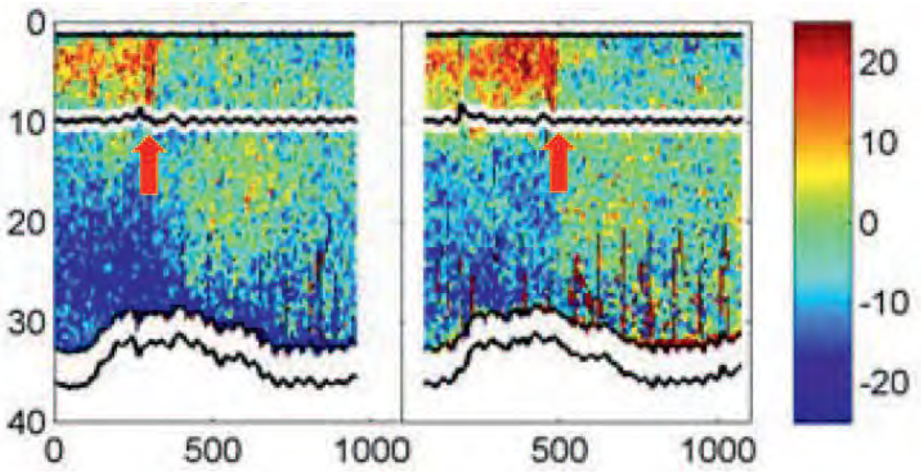

Figure 3. Eastward currents observed from REMUS (at 10m depth) during reciprocal transects. The frontal region is marked. Depth (m), Distance (m), Speed (cm/s). Image: T. Boyd *et al.*, 2010 IEEE AUV Symposium. DOI: 10.1109/AUV.2010.5779670

region triggers internal waves that propagate as packets or as solitary bores. These waves have little surface signature; instead they move along a subsea density interface, like waves inside a bottle filled with layers of oil and water.

The scientists wanted to examine rapidly changing features with small and complex spatial structures. They programmed an AUV, equipped with turbulence sensors as well as up- and down-looking Teledyne RDI ADCPs, to make successive reciprocal passes through these waves.

During two surveys, winter and late spring, the internal waves were found to drive vigorous subsurface mixing, energised by strong vertical shear in the water currents. Viewing transects of water properties and turbulence levels in conjunction with current profiles from the Teledyne RDI ADCPs helped scientists explain abrupt changes in their data sets.

During one survey, the researchers studied an internal bore. Currents, water properties, and turbulence near the propagating front showed striking spatial changes. Successive passes by the AUV revealed not only the eastward advance of the front but the persistence of the altered state in its wake (see figure 3).

Currents ahead of the advancing plume were slight at all depths. However, things changed abruptly at the front with speeds reaching 20 centimetres per second in both upper and deeper layers. Moreover, these two layers were headed in opposite directions, with upper-layer currents tracking the propagating front. This well-defined pattern was found to be spatially persistent along the bore's tail and between successive transects.

During another survey, internal waves were observed to arise at the plume's leading edge, to detach, and to propagate ahead. Their passage left an underwater wake of severe turbulence that enhanced mixing and vertical exchange of water properties.

ADCPs on AUVs

Up- and down-looking acoustic Doppler current profilers on AUVs serve various roles: navigating subsurface by dead-reckoning, measuring strong currents and vertical shear across a subsurface interface, reporting background currents at all depths, and quantifying movements of frontal regions.

ADCPs used in spatial surveys enable end-users to be better informed for describing local circulation patterns, for assessing mechanisms driving ocean processes, and for seeing the spread of contaminating influences.

As well, high-resolution ADCP transects permit detailed comparison with output from coastal circulation models, allowing for validation, calibration, and even refinement of the models.

Significant advantages came from the high-resolution spatial surveys, especially from seeing the same features on several transects. Repeated sightings allowed quantifying horizontal propagation of features, recording the circulation changes due to the front, measuring persistence of mixing after the front passed, and even calculating how a packet of internal waves dispersed from the front.

DEEP-SEA SEARCH – THE USS 'INDIANAPOLIS'

In 2017, a deep-sea search by Paul G. Allen's RV *Petrel* found success in the Western Pacific, discovering the long-lost shipwreck of USS *Indianapolis*, sunk late in World War II.

Crucial to the search were unmanned underwater vehicles, operable to six kilometres depth. These included a REMUS 6000 AUV and BXL-79, a custom-made ROV – each fitted with a Teledyne RDI DVL.

The BXL-79 ROV carried the first Phased Array DVL rated to 6000 metres. For a given size and performance, phased array technology provides greater bottom-tracking range than traditional piston DVLs – in this case, 275 metres from the seabed.

During this search, the AUV examined 600 square miles (1600 square kilometres) of seabed. Each sidescan sonar survey could last 20 hours. The AUV must get to an area, perform a search with precise navigation, and then return to the ship.

When the AUV's sidescan sonar images revealed candidates for a sunken ship, the ROV was deployed. For this closer inspection, the Teledyne RDI DVL enabled steady hovering, allowing full advantage of the ROV's high-definition cameras.

> Reliable navigation not only helped in relocating seabed anomalies revealed in sonar images, but also reduced the need to resurvey. Equally important, the DVL's steady positioning allowed clearer pictures from imaging sonars and cameras

Left: Figure 4. The custom-made BXL-79 remotely operated vehicle being deployed from the research vessel Petrel. *The green arrow in the picture shows the location of the Teledyne RDI Pioneer-300 Doppler velocity log.* Photo courtesy of Paul G. Allen. *Right: Figure 5. The Teledyne RDI Pioneer-300, the first Phased Array DVL rated to a depth of 6000 metres*

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IMPROVED PRODUCTIVITY

The pressing need for improved understanding of the marine environment and its processes has spurred the use of unmanned underwater vehicles.

Although smaller subsea vehicles see varied action – exploring, monitoring, detecting, and tracking – they excel at repeated high-resolution spatial surveys, offering a new solution for sustained time series of ocean observations.

Compared with fixed sensor nets or cast-based sampling from boats, underway measurements from submerged vehicles supply better quality data sets for tasks such as quantifying transport and dispersion in evolving fields. Plus, this method can be more cost-effective and productive for routine, repeated surveys. These higher-level benefits of using smaller subsea vehicles are founded on high-quality navigation and positioning, which in turn rely on low-noise bottom tracking – a long-standing advantage of ADCPs and DVLs from Teledyne RDI.